578

Hydrological Conditions in Clear Lake, Texas, 1958-66

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By

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ABSTRACT

Temperature and salinity data were collected in 1958-66, and dissolved oxygen, dissolved organic nitrogen, and total phosphorus analyses were made on samples collected in 1964-66 in Clear Lake, a small estuary that flows into upper Galveston Bay.

Seasonal trends in bottom water temperature were similar in the different years and were related closely to trends in air temperature. Average water temperatures were lowest (about 13° C.) in January and February and highest (about 31° C.) in July. The rate of warming and cooling was directly related to the magnitude of the annual temperature difference between the warm and cool months.

Salinity ranged from 0.1 to 23.7 p.p.t. (parts per thousand) and was related inversely to stream flow and precipitation. Variations in rainfall resulted in fluctuations in stream flow and these, in turn, were reflected by variations in salinity.

Dissolved organic nitrogen ranged from 23.5 to 171.5 μg. at./l. (microgram atoms per liter) and averaged 66.4 μg.at./l. Total phosphorus ranged from 1.7 to 26.3 μg.at./l. and averaged 8.2 μg.at./l. Phosphorus values increased markedly in July 1966. No correlation existed between nitrogen or phosphorus and stream flow or rainfall.

Dissolved oxygen ranged from 3.8 to 19.3 p.p.m. (parts per million).

INTRODUCTION

The hydrological characteristics of many estuaries bordering the Gulf of Mexico are being altered by water development projects. The effects of these alterations on the aquatic environment are difficult to document because water quality data are usually not available for the period preceding the alterations.

Clear Lake, a small estuary that flows into upper Galveston Bay, is an area being altered because of a rapidly expanding population. About one-quarter of a million people inhabit the watershed of Clear Lake, and the population is expected to increase to one million in 10 years (Mock, 1965). Hydrological data now available may be used to establish standards for preserving aquatic life in Clear Lake when we learn the physiological requirements of estuarine species and when we know the influence of the changing environment upon these animals.

Personnel of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Tex., collected hydrological data from Clear Lake from 1958 through 1966. This report (1) summarizes the temperature and salinity data for the 9-year period, (2) summarizes the dissolved oxygen, organic nitrogen, and total phosphorus data collected from 1964 through 1966, and (3) compares these variables with air temperature, stream flow, and local precipitation.

STUDY AREA AND SAMPLING PROCEDURES

Clear Lake is about 4 km. (2.5 statute miles) long, less than 2 km. (1 mile) wide, and has a surface area of about 405 ha. (1,000 acres). Average water depth, excluding a 2-m. channel dredged through the lake, is about 1 m. at mean low tide. Stations at which measurements were made during at least 1 year of the study are shown in figure 1. The sampling frequency and type of information obtained each year are listed by stations in table 1.

Salinity and temperature were measured near the bottom (1) with a portable salinometer having an accuracy of ±0.3 p.p.t. (parts per thousand) and ±0.5° C., or (2) by titration of water samples (accuracy, ±0.2 p.p.t.) and direct readings with a glass thermometer (accuracy, ±0.5° C.). Water samples were taken with a

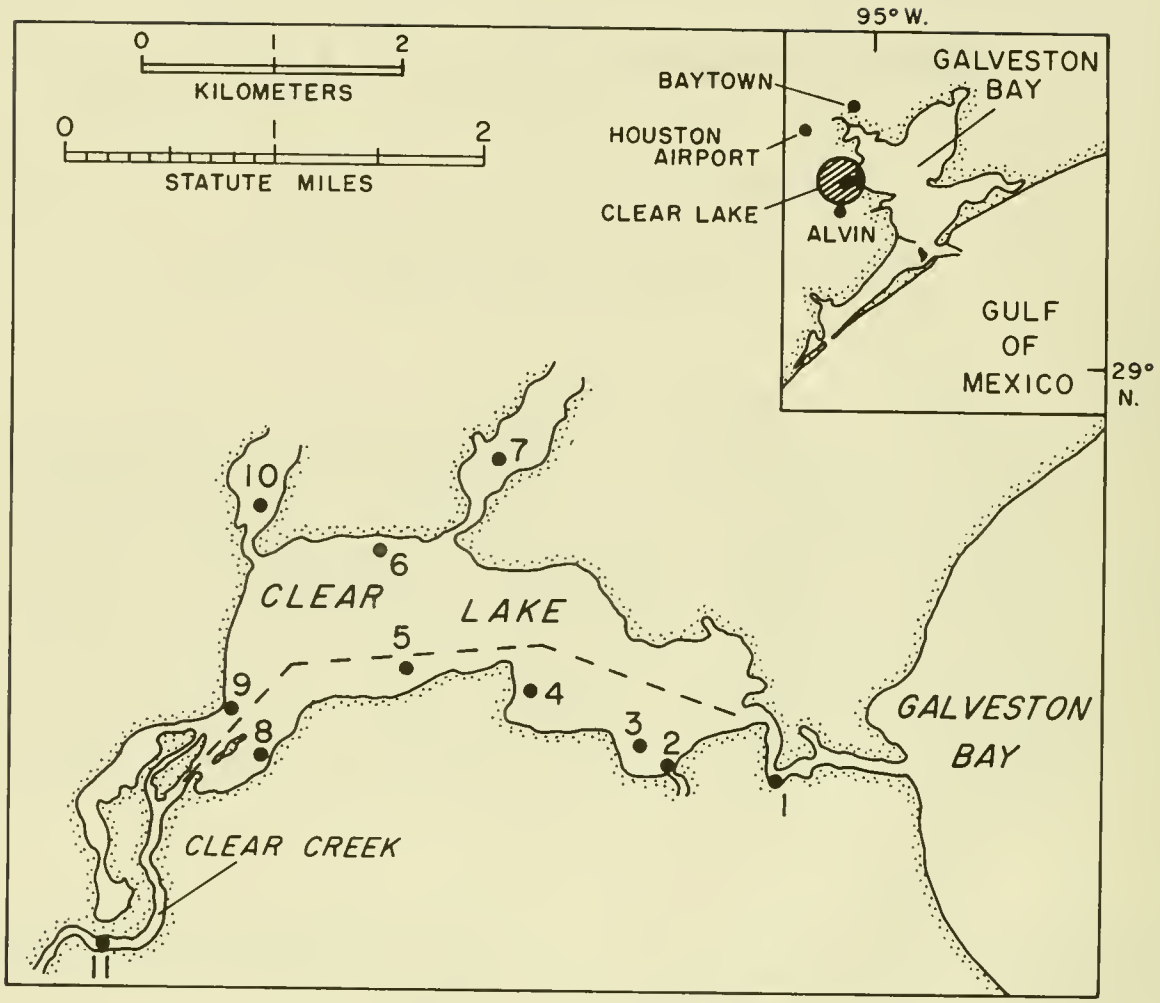

Figure 1.--Galveston Bay system and Clear Lake, Tex., showing sampling stations.

Table 1.--Station number, frequency of sampling, and type of information obtained from Clear Lake, Tex., 1958-66

Year	Station number	Sampling frequency[1]			Type of information obtained				
		Weekly	Semi-monthly	Monthly	Temperature	Salinity	Oxygen	Organic nitrogen	Total phosphorus
1958...	1, 3-7, 10-11	x	-	-	x	x	-	-	-
1959...	1, 3-7, 10-11	x	x	x	x	x	-	-	-
1960...	4-7, 11	-	x	-	x	x	-	-	-
1961...	4-7, 11	x	x	-	x	x	-	-	-
1962...	4-5, 7, 11	x	x	-	x	x	-	-	-
1963...	3, 7	-	x	-	x	x	-	-	-
1964...	3, 6-8	-	x	x	x	x	x	x	x
1965...	2-3, 8-9	x	x	x	x	x	x	x	x
1966...	2-3, 8	x	x	-	x	x	x	x	x

[1] Sampling frequency varied within some years.

Table 2.--Range in bottom temperature in Clear Lake, Tex., 1958-66

Month	Year								
	1958	1959	1960	1961	1962	1963	1964	1965	1966
	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
January....	11.3-15.0	4.8-19.8	14.0-18.3	10.5-13.7	6.0-14.5	2.9-15.2	13.0-15.0	11.6	16.0
February...	8.0-16.8	8.6-20.9	-	9.0-17.5	12.0-18.0	5.3-13.4	13.0-19.0	9.5-17.0	10.0-11.0
March.....	15.2-20.2	15.4-20.9	-	18.2-20.5	14.0-18.5	16.2-21.7	20.4-23.0	11.0-21.0	15.0-27.0
April.....	19.0-28.7	18.0-22.4	-	16.7-22.0	16.0-26.0	21.4-26.4	21.0-21.5	19.0-29.2	19.5-28.0
May.....	24.8-32.6	-	25.4-28.7	24.3-28.0	-	27.0-29.0	28.1-30.5	23.0-30.8	20.5-30.0
June.....	28.5-33.9	29.8-31.8	27.9-30.0	27.7-28.7	30.0-33.0	31.0	27.0-29.2	28.0-32.0	26.0-36.0
July.....	28.8-34.4	29.1-33.2	28.8-32.0	24.5-28.5	31.0-33.0	31.0-34.0	29.5-33.6	27.0-33.0	29.0-34.0
August.....	27.5-34.0	27.0-35.0	28.5-31.6	27.9-29.6	29.0-31.0	30.0-33.0	32.3-33.0	28.0-32.0	24.0-31.0
September..	24.0-33.0	28.0-29.0	25.7-30.8	25.0-30.8	-	29.0-31.5	26.6-28.0	22.0-33.3	24.0-33.0
October....	19.0-26.8	20.2-21.4	20.0-26.8	18.0-24.4	22.5-23.4	24.0-27.0	22.4-23.0	16.0-26.0	18.0-24.0
November...	17.1-23.4	10.9-11.1	18.6-22.0	16.0-19.5	13.0	20.5-22.0	21.2-25.1	18.0-23.0	16.0-21.0
December...	9.5-16.0	14.0-17.7	7.9-15.5	10.5-13.0	13.2-13.5	9.0-12.0	11.0-13.0	11.0-19.0	19.0
Annual.....	8.0-34.4	4.8-35.0	7.9-32.0	9.0-30.8	6.0-33.0	2.9-34.0	11.0-33.6	9.5-33.3	10.0-36.0

- = no data

Kemmerer[1] or a triple-bottle sampler. Beginning in 1964, dissolved oxygen, in p.p.m. and dissolved organic nitrogen and total phosphorus in μg.at./l. (microgram atoms per liter) were determined from samples of bottom water.

The techniques for salinity, oxygen, and phosphorus determinations were described by Marvin, Zein-Eldin, May, and Lansford (1960), and organic nitrogen was determined by a Kjeldahl method described by D. C. Willis.[2]

Air temperature and rainfall data near Clear Lake were obtained from the U.S. Weather Bureau Climatological Data collected at Baytown, Houston Airport, and Alvin, Tex. (fig. 1); these data were averaged to obtain mean values.

Measurements of stream flow for Clear Creek, the major tributary entering Clear Lake, were obtained from the U.S. Geological Survey.

TEMPERATURE

The method of combining temperature data is based on an analysis of data collected in 1958 when bottom water temperatures were taken weekly at all stations except 2, 8, and 9 (fig. 1). Temperatures taken at eight stations on a given date throughout the year were compared by analysis of variance. Since values did not vary significantly between stations ($F = 0.37$; $F_{.05}$ for 7 and 376 d.f. = 2.04), data from all stations were combined to compute monthly averages. Table 2 shows the ranges of temperatures from which these average monthly values were computed.

Trends in water temperature were similar between years, although the yearly ranges varied (fig. 2). The seasonal cycles of water temperature and air temperature were related closely. The large and nearly constant differences between air and water temperatures are probably not real, because average air temperatures were derived from observations over a 24-hour period, whereas average water temperatures were based on measurements made randomly during daylight. Water temperatures were lowest (about 13° C.) in January and February and began increasing gradually in March; they were highest (about 31° C.) in July and began declining in August and September. Monthly averages ranged from 8.7° to 32.7° C. The greatest difference in average minimum temperatures between years was about 3° C. (1963 and 1965), and the greatest difference in average maximum temperatures was about 5° C. (1961 and 1963).

Year-to-year variations were apparent in the warming and cooling rates of the water in Clear Lake (fig. 3). These rates were determined by computing the slopes of the temperature curves (fig. 2) during January through July (warming period) and August through December (cooling period) for each year. Waters warmed and cooled rapidly in 1958, 1959, 1962, and 1963 but slowly in 1960, 1961, 1964, 1965, and 1966.

The rate of warming and cooling of water each year was directly related to the magnitude of the difference in average temperatures between the summer (June, July, and August) and the preceding winter (December, January, and February)--see figure 3. This relation is illustrated by a comparison of the values for 1960 and 1963. In 1960, when temperatures increased 2.3° C. per month in the spring and decreased 3.6° C. per month in the fall, the difference between the warm and cool months was 13.7° C. In 1963, in contrast, when

[1] Trade names referred to in this publication do not imply endorsement of the commercial products.

[2] The Kjeldahl method was modified by D. C. Willis, University of Tampa, Florida, for the analysis of dissolved organic nitrogen in estuarine water (unpublished).

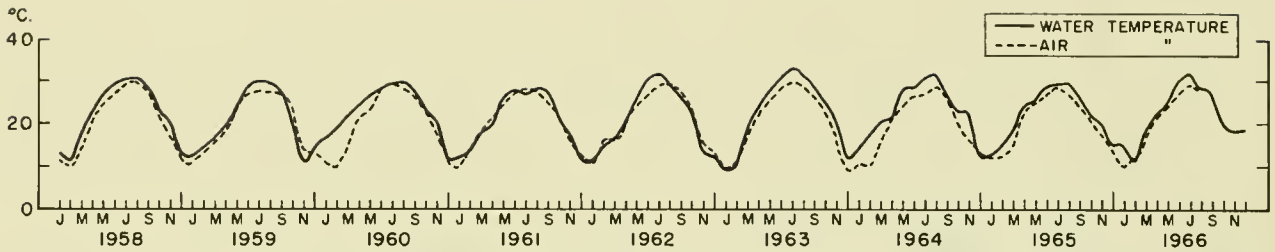

Figure 2.--Average monthly water temperatures for Clear Lake, Tex. (1958-66), and monthly average air temperatures recorded by the U.S. Weather Bureau

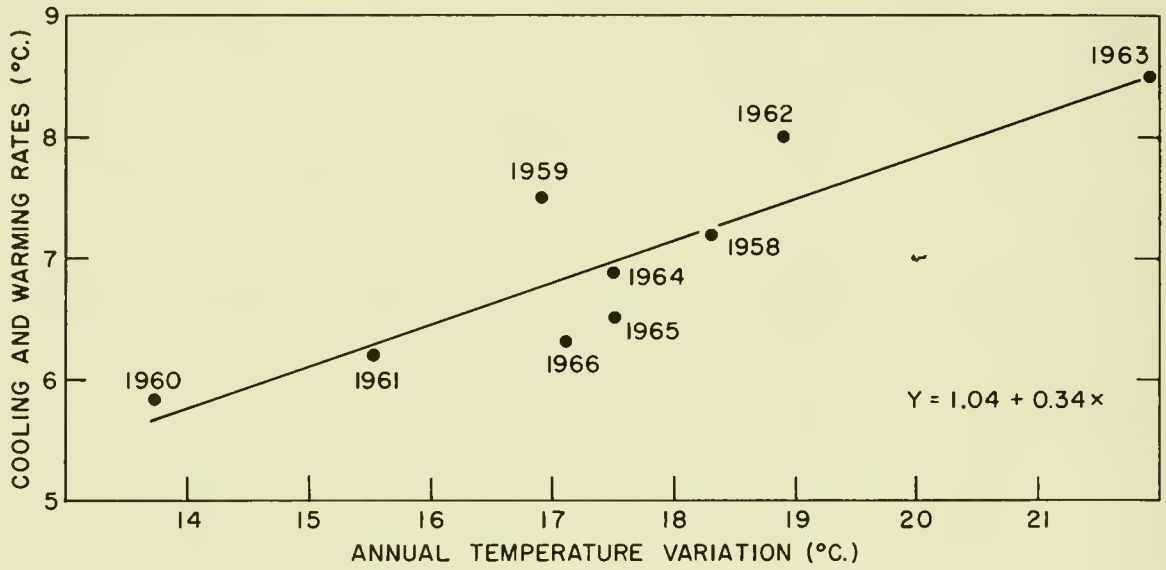

Figure 3.--Sum of the cooling and warming rates in relation to the annual temperature variation in Clear Lake, Tex. (1958-66).

Table 3.--Range in bottom salinity in Clear Lake, Tex., 1958-66

Month	Year								
	1958	1959	1960	1961	1962	1963	1964	1965	1966
	P.p.t.	P.p.t.	P.p.t.	P.p.t.	P.p.t.	P.p.t.	P.p.t.	P.p.t.	P.p.t.
January....	0.1- 8.6	15.2-21.3	-	0.1- 3.2	14.3-17.5	2.1-13.6	10.6-17.7	17.1	14.4
February...	0.1- 7.3	0.2- 3.2	-	0.2- 2.2	13.8-17.7	5.9-12.2	0.7-14.0	16.4-18.8	2.4- 2.5
March.....	1.4- 9.9	0.2- 7.8	-	1.2- 5.6	14.9-16.3	7.1-13.8	10.3-13.0	12.0-17.0	8.0-13.9
April.....	3.0-13.6	-	-	5.0- 9.2	9.7-16.7	13.7-18.6	13.6-15.6	9.9-16.6	0.5-16.0
May.....	7.9-14.7	-	6.4-13.3	5.6-10.3	15.2	16.3-18.2	0.4-15.2	6.8-16.7	0.3- 4.3
June.....	5.3- 8.2	1.3- 8.2	0.2-14.6	0.4-10.0	7.3- 8.6	16.2-18.7	14.4-19.8	8.0-13.1	1.2- 5.0
July.....	5.9- 9.1	0.2- 6.2	2.5- 7.5	0.1- 2.3	6.3-13.6	8.6-16.2	16.5-17.9	8.0- 9.5	7.0-11.5
August.....	4.6-14.4	0.8- 4.2	0.5- 8.1	3.4- 9.6	12.9-15.0	13.7-21.1	16.4-18.2	14.7-19.9	5.3-13.5
September..	0.1-16.0	8.1	2.9-11.5	0.7-10.1	-	18.7-23.1	19.5-20.5	17.0-21.4	7.5-12.5
October....	2.3- 9.2	0.3-12.7	0.9-12.1	1.8-13.6	12.1-14.5	21.0-23.4	18.3-19.6	19.0-21.0	13.4-20.0
November...	6.5-11.4	10.0-12.8	4.2- 7.6	0.1-10.5	14.2	16.4-23.7	14.4-21.2	9.8-22.4	11.6-17.4
December...	8.6-18.3	0.5-16.4	0.1- 4.9	4.5-10.0	11.5-14.0	10.6-22.9	0.8- 3.3	3.2-19.3	19.2
Annual.....	0.1-18.3	0.2-21.3	0.1-14.6	0.1-13.6	6.3-17.7	2.1-23.7	0.4-21.2	3.2-22.4	0.3-20.0

- = no data

temperatures increased 4.4° C. per month in the spring and decreased 4.1° C. per month in the fall, the range between the warm and cool months was 21.9° C.

SALINITY

Salinities in Clear Lake ranged from 0.1 to 23.7 p.p.t. during the study (table 3). I compared the 1958 data by using analysis of variance in the same manner as for temperature. Differences between stations were significant ($F = 5.68$, $F_{.05}$ for 7 and 376 d.f. = 2.04). Duncan's multiple range test (Steel and Torrie, 1960) was used to determine the salinity zones shown in figure 4.

Average monthly salinities were nearly always lower in zone IV than in zone I (fig. 5), and were usually intermediate in zones II and III. Because collections were made only in zones II and III for the entire 9 years, data from these two zones were used to evaluate fluctuations over the 9-year period.

Salinity trends for the 9 years are shown in figure 6. Yearly averages were relatively low from 1958 through 1961 (grand average, about 8 p.p.t.), and generally high in 1962 through 1965 (grand average, about 13 p.p.t.). Average salinity in the lake dropped below 10 p.p.t. in 1966. The annual average salinity was highest (15.9 p.p.t.) in 1963 and lowest (4.8 p.p.t.) in 1961.

Average monthly stream flow in Clear Creek also is compared with salinity of Clear Lake in figure 6. In general, stream flow was related inversely to salinity during the period of comparison. The correlation coefficient (r) was -0.57.

The correlation between monthly average salinity and local precipitation is not as apparent ($r = -0.41$) as when the data are grouped by 4-month intervals. The use of 4-month average salinities and total rainfall during the same periods reduces variation in the data, as indicated by a correlation coefficient of -0.57. When these values were used, trends in the data became apparent (fig. 7). For example, in 1959-61, when rainfall was considerably higher than the 9-year average, salinities in the lake were low; in 1962-65, when rainfall was below the 9-year average, salinities in the lake were correspondingly high. Variations in rainfall from year to year coincided with fluctuations in stream flow and these, in turn, were reflected by variations in the salinity of Clear Lake.

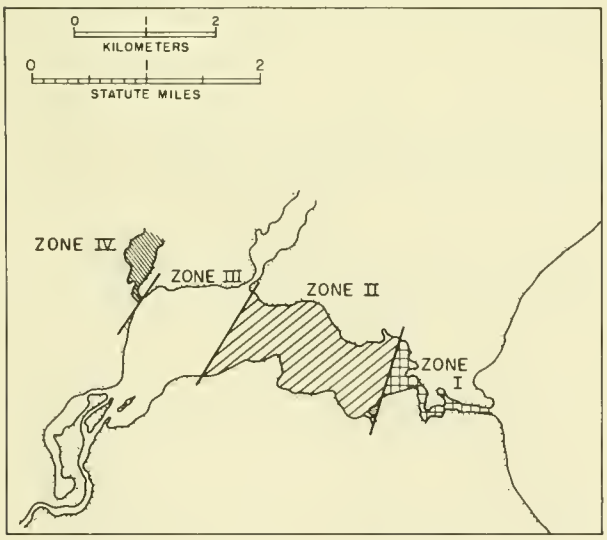

Figure 4.--Clear Lake, Tex. divided into zones of different salinities.

DISSOLVED ORGANIC NITROGEN

Dissolved organic nitrogen ranged from 23.5 to 171.5 μg.at./l. (table 4). Monthly averages were computed by combining data from all stations; the lowest and highest average values (33.8 and 171.5 μg.at./l.) were recorded in 1964. Monthly mean values in table 4 show that nitrogen fluctuated erratically and had no obvious seasonal pattern. Neither river discharge ($r = 0.08$) nor rainfall ($r = -0.05$) was correlated with nitrogen.

Dissolved organic nitrogen averaged 66.4 μg.at./l. over the 3 years.

TOTAL PHOSPHORUS

The concentration of total phosphorus ranged from 1.7 to 26.3 μg.at./l. (table 5). Monthly mean values fluctuated between 4.7 and 12.1 μg.at./l. from 1964 through 1965 and reached a minimum of 3.7 μg.at./l. in March 1966. A gradual increase from April through June 1966 was followed by a marked increase in July. Values remained high for the rest of the year, and the maximum mean was 18.8 μg.at./l. in November. Stream flow ($r = -0.24$) and rainfall ($r = -0.07$) were not correlated with phosphorus.

The high phosphorus recorded in Clear Lake in the summer and fall of 1966 probably resulted from intrusion of water from upper Galveston Bay, where the phosphorus varied from 10.9 to 25.0 μg.at./l. at that time (Pullen, unpublished data). Dye studies made in a model of the Galveston Bay system show a marked interchange of water between upper Galveston Bay and Clear Lake (U.S. Corps of Engineers, personal communication).

Total phosphorus in Clear Lake averaged 8.2 μg.at./l. for the 3 years.

OXYGEN

Dissolved oxygen ranged from 3.8 to 19.3 p.p.m. during this study (table 6). Mean monthly values for 1965 and 1966 indicate a seasonal

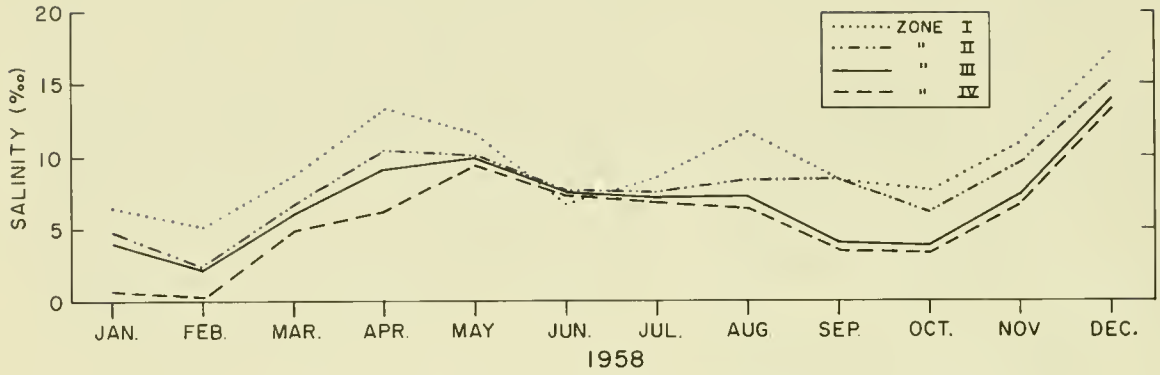

Figure 5.--Average monthly salinity by zone in Clear Lake, Tex., 1958.

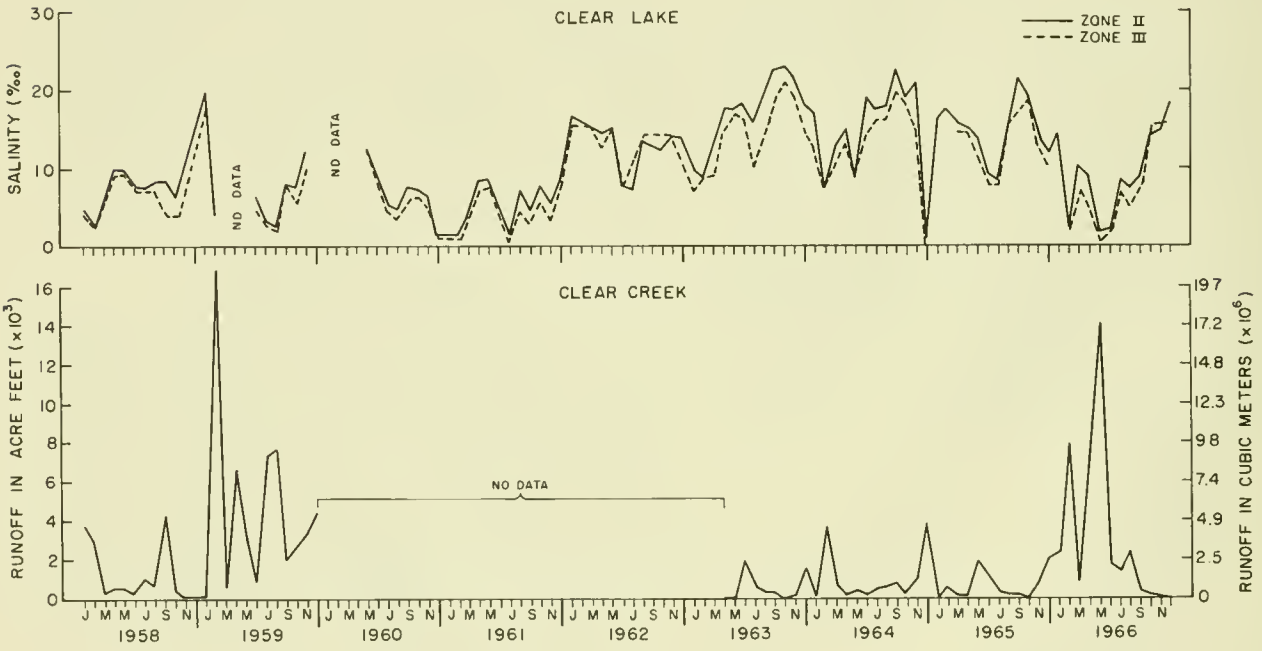

Figure 6.--Average monthly salinity and stream flow into Clear Lake, Tex. (1958-66). The Clear Creek gaging station was not in operation from May 1960 through May 1963.

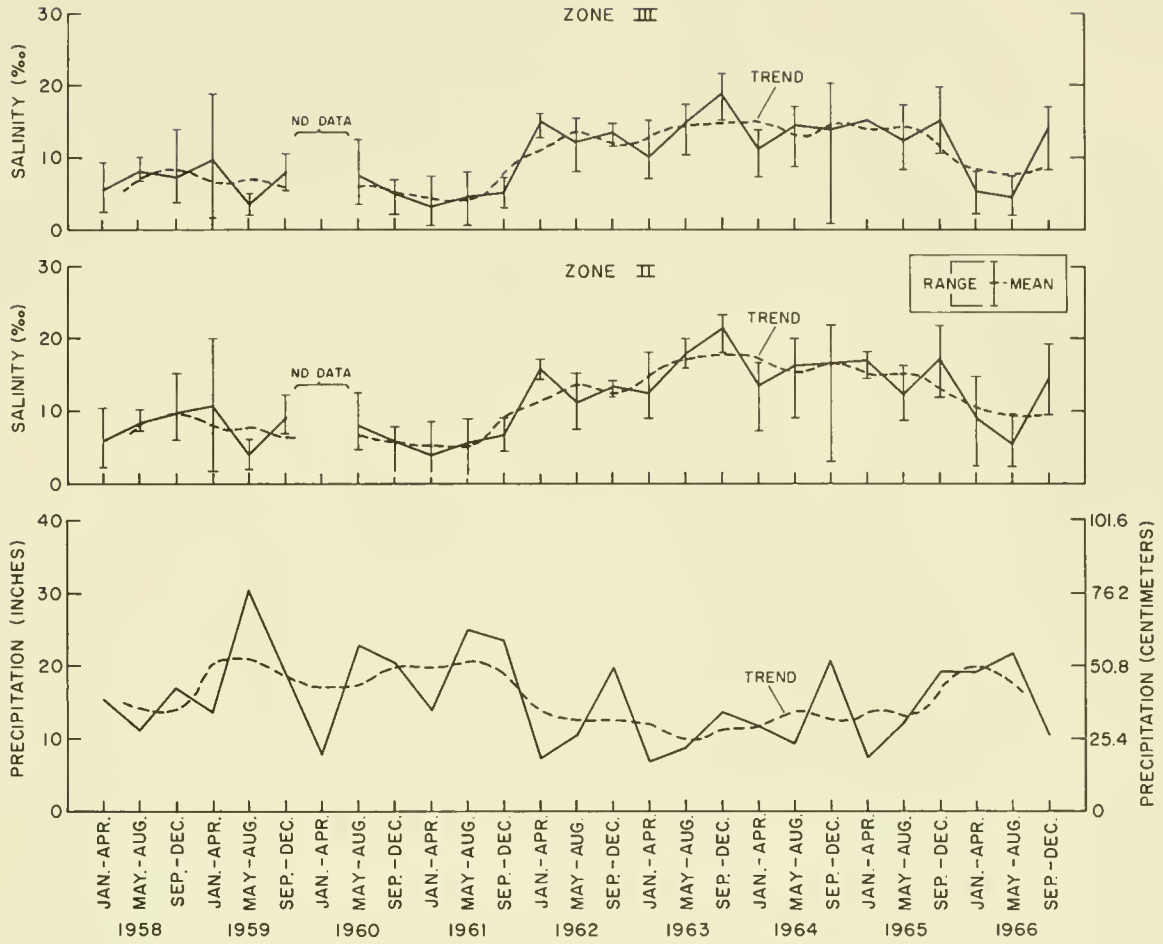

Figure 7.--Cumulative local precipitation and range and average salinity in Clear Lake, Tex., for 4-month periods. Trend lines were plotted by using three-point moving average.

Table 4.--Monthly range and mean of dissolved organic nitrogen in Clear Lake, Tex., 1964-66

Month	1964		1965		1966	
	Range	Mean	Range	Mean	Range	Mean
	μg. at. /l.		μg. at. /l.		μg. at. /l.	
January	-	-	(1)	54.2	(1)	40.7
February	-	-	50.6- 72.9	56.1	(1)	104.3
March	-	-	52.2-134.0	84.3	28.2- 45.1	36.8
April	(1)	171.5	33.7- 57.5	39.9	44.7-103.5	70.4
May	(1)	90.6	34.5- 57.5	58.4	23.5-121.0	72.9
June	(1)	33.8	50.0- 78.9	67.4	33.5-105.0	59.6
July	(1)	117.5	50.5- 78.4	68.7	40.5-139.0	70.4
August	(1)	69.0	25.8- 87.0	56.5	58.0-132.0	107.2
September	(1)	37.3	66.1- 76.6	71.3	63.5- 74.3	68.4
October	(1)	88.1	41.2- 47.5	44.3	68.5- 97.0	78.5
November	(1)	73.7	62.6- 83.1	70.2	37.0- 72.5	53.5
December	(1)	58.0	59.9- 81.3	67.4	57.5-106.0	81.7
Year	33.8-171.5	82.2	25.8-134.0	62.1	23.5-139.0	68.6

- = no data [1] Single observation

Table 5.--Monthly range and mean of total phosphorus in Clear Lake, Tex., 1964-66

Month	1964		1965		1966	
	Range	Mean	Range	Mean	Range	Mean
	μg. at. /l.		μg. at. /l.		μg. at. /l.	
January	-	-	(1)	5.9	(1)	12.3
February	-	-	6.4- 9.5	8.1	(1)	4.9
March	-	-	6.9-15.7	11.1	1.7- 4.7	3.7
April	(1)	10.1	1.7- 8.3	4.7	3.1- 7.5	4.7
May	(1)	9.5	4.6- 6.8	5.6	3.2- 7.4	5.7
June	(1)	8.9	4.9- 8.4	6.9	3.3-10.8	6.2
July	(1)	9.4	6.7- 7.4	7.1	11.6-15.0	13.0
August	(1)	8.1	5.1- 5.8	5.4	10.3-26.3	14.8
September	(1)	10.0	4.7- 6.0	5.4	13.4-16.9	15.2
October	(1)	7.3	6.1- 7.2	6.7	11.2-15.3	13.4
November	(1)	12.1	4.4- 5.9	5.2	15.9-21.4	18.8
December	(1)	5.7	5.0-10.1	7.5	13.8-17.7	15.7
Annual	5.7-12.1	9.0	1.7-15.7	6.9	1.7-26.3	9.6

- = no data [1] Single observation

Table 6.--Monthly range and mean of dissolved oxygen in Clear Lake, Tex., 1964-66

Month	1964		1965		1966	
	Range	Mean	Range	Mean	Range	Mean
	P.p.m.		P.p.m.		P.p.m.	
January	-	-	(1)	17.0	(1)	12.8
February	-	-	7.6-10.6	9.1	-	-
March	(1)	19.3	3.8-15.4	9.3	(1)	10.3
April	(1)	12.5	8.6- 9.8	9.2	7.6-11.5	8.8
May	(1)	11.4	5.7- 8.8	7.5	5.8- 7.5	6.9
June	(1)	9.3	5.5- 8.4	7.0	4.6- 7.2	6.7
July	(1)	10.0	(1)	6.4	6.3-10.1	8.2
August	(1)	7.4	5.0- 6.7	5.8	5.7- 8.8	7.2
September	(1)	9.9	(1)	6.6	3.8-12.4	8.1
October	(1)	16.3	5.9- 9.4	7.5	(1)	10.4
November	(1)	10.6	9.4-11.7	10.6	(1)	11.3
December	(1)	8.6	8.6- 9.6	9.1	-	-
Annual	7.4-19.3	11.5	3.8-17.0	8.4	3.8-12.8	8.2

- = no data [1] Single observation

trend, but because of wide fluctuations in values within a month and in sampling frequency, these trends are probably not significant.

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